Background Paper

CANADIAN INSTITUTE FOR INTERNATIONAL PEACE AND SECURITY

Number 3 March 1986

NUCLEAR WINTER

by Leonard Bertin

In the 40 years since Hiroshima, most of the concern expressed about the possible further use of nuclear weapons has focussed on fire, blast, resultant injuries, immediate and delayed effects of radiation, and on the likely collapse of social regulatory systems.

With the recent development of sophisticated computer systems for simulating weather, climate and atmospheric transport of pollutants, an additional burden of concern is the possibility of devastating climatic disturbances that may follow the use of nuclear weapons, especially if cities are included among the targets.

The term "nuclear winter" has been used by many scientists to describe what they have come to believe could be the inevitable consequence of any major exchange of nuclear weapons. The expression nuclear winter is disliked by some of the strongest proponents of the theory, because they find it "too sensational" even though, if the theory is correct, it could herald consequences a billion times worse than any single murder that makes banner headlines in a newspaper. The phrase has, however, acquired growing acceptance, because of its use in many respected scientific journals.

THE THEORY

In 1983, two important papers regarding the effects of nuclear explosions appeared in *Science*, the prestigious print rostrum of the American Association for the Advancement of Science. The first,[1] now generally referred to as TTAPS (the initials of its five authors) spelled out what the writers, all eminent in their own fields of scientific specialization, believed could be the awesome global climatic consequences of any widescale use of large nuclear weapons. The second,[2] bearing the names of no less than 20 scientists, described what those authors considered could be the potentially horrendous biological consequences of such climatic changes. One author common to both papers was Dr. Carl Sagan of Cornell University, whose name has probably been the one most commonly associated with the nuclear winter hypothesis.

The conclusions were that, if cities were attacked, either because of their nearness to important military or industrial targets or to achieve political objectives, hundreds of millions of tons of smoke and soot produced by fires might obscure sunlight that is essential to life on earth for weeks or months. The result could be to create, in the critical combat latitudes of 30° to 70° North which are among the more densely populated zones of the earth, day-long darkness with attendant temperatures of minus 10 to minus 40 Celsius. The entire harvest of some of the world's most important food-producing areas, including those of the United States, Canada, the European Economic Community and, of course, the Union of Soviet Socialist Republics, could be wiped out.

Imagine the plight of frightened survivors, attempting a life below ground, devoid of telephones and electricity — for grid systems would be among the first casualties of nuclear war — without pumped water, gasoline or fuel oil, without mobile police and ambulance services and, probably, without hospitals. Add to this the spectre of frozen lakes and reservoirs. Widespread famine and death by starvation, if not from dehydration, would be inevitable.

The seeds of this concern are not new. In 1965, Professor Robert Ayres, after three years study at the Hudson Institute, a strategic "think tank", produced three volumes that portended such a situation.[3] It suggested that global climate could be seriously affected by nuclear war.

The attention accorded to any new scientific or technological development is too often, and nearly always, determined by the political climate at the time and by competing events: the Vietnam War was the focus of media attention from 1965 until the early 1970's. Dr. Ayres' predictions collected dust on shelves.

In 1971, a group at Cornell University, led by Carl Sagan, had become interested in data transmitted by Mariner 9, the first man-made satellite to circle the planet Mars. They tried to relate observed dust storms with low surface temperatures measured on that planet.

Attention again focussed on the climatological implications of dust when a group at the University of California, headed by Professor Louis E. Alvarez, postulated yet another possible explanation for the still unexplained sudden disappearance of dinosaurs some 65 million years ago. It could, they suggested, be the result of climatological changes produced when a large meteorite collided with Earth and created huge global dust clouds that cut off sunlight and thus destroyed the plants on which the animals fed.[4]

The potential role of the fine soot particles, less than a millionth of a metre in diameter, produced chemically by fires (as opposed to physically scattered dust, which usually comprises particles more than a millionth of a metre across) was stressed in June 1982. Particles of this size and these chemical and physical characteristics (they are usually black) tend to be very absorptive of sunlight. Dr. Paul J. Crutzen, now with the Max Planck Institute of Chemistry, and Dr. John W. Birks of the University of Colorado contributed a paper to a special volume of *Ambio*, the journal of the Royal Swedish Academy of Science. In it they concluded that soot particles generated by urban and industrial fires caused by nuclear bombardment might, because of their small size, remain aloft for many weeks and be a more critical factor than dust.[5]

Early in 1983, the US Defense Nuclear Agency asked the US National Research Council to assess this situation. A committee of specialists was formed; it reported, in December 1984, on the effects on the atmosphere of a major nuclear exchange.[6] The Canadian Government meanwhile asked the Royal Society of Canada to make an independent study. Their report, "Nuclear Winter and Associated Effects," appeared in January 1985.[7]

The warfare scenarios of weapons used by Crutzen and Birks, the TTAPS group and their biological colleagues, the US NRC and by the Royal Society of Canada Committee are broadly similar. All assume that between one-third and one-half of the world's known arsenals of nuclear weapons would be committed. This would call for detonation of warheads with a total energy release in a bracket equivalent to between 5,000 and 6,500 millions of tons (MT) of conventional high explosive.

A separate study, carried out by Dr. Vladimir V. Aleksandrov and colleagues in the Computer Institute of the Soviet Academy of Sciences[8] used a similar scenario as the basis for its computer modelling and its conclusions are perhaps the gloomiest of all.

The US NRC Committee, which probably had the best access to data on nuclear weapons, adopted as its baseline scenario the detonation of a total of 6,500 MT. They postulated that, of this total, 1,500 MT would be set off at ground level, mainly in "counterforce strikes" against hardened ballistic missile silos and communications and control centres. The remaining 5,000 MT would be set off at altitudes calculated to maximize blast damage to structures, of which 1,500 MT would be targeted at military, economic and political targets that are coincidentally situated in or near 1,000 urban centres.

It should be said here that atmospheric scientists make many distinctions among the various layers of the air above us. The two principal layers that they recognize are the highly dynamic lower layer, or *troposphere*, which extends to an altitude of about 10 km, and becomes cooler with height; and the *stratosphere*, where there is virtually no vertical temperature gradient and, consequently, negligible convection mixing. The boundary between these layers, a quite real natural frontier, is called the *tropopause*.

The US NRC scenario assumed that in fiercely burning city fires about three-quarters of all combustible material available would be consumed and that hundreds of millions of tons of smoke and dust would be injected into the atmosphere. It further calculated that, for each MT of nuclear explosive detonated, one-third of a million tons of combustion products would be deposited in the stratosphere. Of this total, about eight per cent would be soot that, because of its small particle size, would be likely to remain aloft for long periods.

The scenario foresaw that certain processes would diminish light scattering and light absorption. Some smoke particles would coagulate with one another in the rising plumes and become larger and denser and fall, while in moist areas, water vapour would be entrained and/or condensed. It was assumed that 50 per cent of smoke in the tropopause would be "rained out" by moisture in this way. The rest of the smoke would be uniformly distributed vertically at heights of zero to nine kilometres.

Initially, and for some weeks, lateral distribution would be non-uniform. The committee concluded that, in areas covered by the initial hemispheric smoke load, light levels could be reduced by a factor of up to 100. Because industrialized nations tend to concentrate a large proportion of their resources and combustible materials in the vicinity of the central areas of large cities, it was concluded that even a small fraction of the existing nuclear arsenals — say 100 MT — could, if directed at urban areas, gener-

ate nearly as much smoke as the 6,500 MT of the baseline scenario, when distributed over much larger rural areas.

DISCUSSION

The NRC Committee stressed the uncertainties in its calculations of vertical distribution of smoke and the subsequent fates of the various materials. The Committee stressed that accurate detailed forecasts of the way the atmosphere might behave are difficult to achieve. The duration of any effects, it stated, lie beyond the present state of knowledge. It warned that some future study, conducted at a time when the data and modelling techniques have been improved, could produce quite different analyses and conclusions. It nevertheless found there was a clear possibility that great portions of the land areas of the northern temperature zone (and perhaps a large segment of the planet) could be severely affected.

The Canadian committee reached similar general conclusions that major, if temporary, climatic upsets would follow nuclear war. It found the data provided by various models to be plausible but emphasized that the uncertainties are formidable. Even so, the report states, "a *prima facie* case has been made that nuclear winter will indeed follow a wide-range of attacks."

Dr. Kenneth Hare, a climatologist of world renown who chaired the Royal Society Committee, identifies some of the unknowns that are crucial to any proper understanding of the problem. Speaking of the hypothetical situation if missile silos in North Dakota near the Canadian border were attacked, he says: "If there are ground bursts, then clearly you are going to have a lot of vaporization. You would have to take each vapor separately. Most vapors are surprisingly disinclined to self-coagulate and precipitate. It has first to coagulate. It will remain a vapor, and therefore not fall, until you provide condensation nuclei." Many particulates, including some components of smoke, at first show no inclination to join with water vapour. Others attract water and thus contribute to the formation of droplets. Some that are similar in crystalline form to ice, such as silver iodide, have been successfully used for seeding clouds of water vapour to alleviate drought but, as Dr. Hare pointed out, such similarity is not essential. Platelets of clay, floating round in the atmosphere, can perform the same function.

One of the major climatic problems seen as resulting from a nuclear exchange is a colossal inversion layer, caused by smoke aloft that absorbs solar energy, gets warm, and puts an effective "lid" on all weather systems.

What would nuclear winter be like in Canada? If an attack occurred in winter, the implications for weather and vegetation would be far less serious than for one in summer. "Take a typical winter," says Dr. Hare, "Set a big high cold system over the Great Lakes and you have North America looking like nuclear winter. It is rehearsed *every* winter." Crops might not suffer, but there could be darkness 24 hours a day.

In summer, the consequences would be horrendous. Dr. Thomas Hutchinson, professor of botany at the University of Toronto and a member of the Royal Society committee, points out that crops are extremely sensitive to sudden temperature switches, and especially vulnerable to sudden frosts and extended cold periods. "If there is a drop in temperature of any more than two degrees, wheat production is pretty well out over the whole growing season. It will reduce the growing season to the point where you cannot produce a crop. Severe frosts in the middle of the growing season would be devastating."

Dr. Hutchinson explains that many Canadian plants are adapted to cold. At certain times in the year they react to certain stimuli and in their own way prepare for drops in temperature. In the spring, as they start to grow again, they lose the ability. Temperature tolerance is not just a problem of the colder latitudes. "If you look at the tropics," says Dr. Hutchinson, "you will find a lot of plants that cannot even tolerate temperatures as low as 10 C. A lot of them will be killed."

How long can the Earth's own heat reserves protect a plant? In some cases, for less than one day. Professor Hutchinson explains that the damage is done by formation of ice crystals within cells. In relatively temperate climates plants (and some animals) reduce their water content in winter and thereby increase the concentration of dissolved chemicals. It is, he explained, the equivalent of adding anti-freeze. Other plants, such as those in alpine and arctic tundra that are subjected regularly each year to minus 40 C, have a self-securing mechanism that eliminates water from their cells.

Could the whole concept of nuclear winter be just a scare? "The whole thing is scenario-dependent," says Dr. Hutchinson. "None of the groups say this or that will happen. None of them are prepared to state the sequence of detonations that could take place. They look at a wide range of scenarios. At the lower end, you can get out of nuclear winter. There will be some scenarios where the numbers and sizes of detonations will be small, too dispersed or too high to cause a major climatic problem. A detonation has to be at or near the ground to project dust and smoke into the upper atmosphere."

Dr. Hutchinson, by the way, is one of those who does not like the term nuclear winter. "None of us like it," he says, "It is too dramatic. It conjures up a certain sort of image. It also distracts attention from other important things like changes in precipitation and changes in ultraviolet radiation, the generation of toxic chemicals and acid pollutants. We have to get used to the fact that, if we get into this, we are going to be living in a thin acid fog. We are going to have very many nasty toxic chemicals produced by plastics that are burned. Things look really grim, if we get into a major nuclear exchange."

Dr. Hare summed up: "I think that some people feel that there may be a terrible bomb dropped on Toronto or Montreal or Vancouver and the rest of the country might suffer a bit from fall-out. Instead, we have to consider the possibility of enormous numbers of these bloody great bombs dropping on our cities."

Dr. Andrew Forester, scientific director of the Royal Society study, author of most of it and editor of all of it, was asked whether he had any personal doubts about the nuclear winter concept, and admitted that there had to be. "But," he said, "I detect a growing consensus, that a nuclear winter, after a nuclear exchange, is more likely than less likely. That impresses me because, when you go to a conference with a lot of people who are experts and you detect a growing feeling that nuclear winter is a possibility, then you have to be persuaded, no matter what your own intuitive feelings may be. It is my perception that nuclear winter will be less severe than was originally proposed but that there is more and more certainty that, given the right conditions, winter will occur. It is both good news and bad news."

What also strikes Dr. Forester as "persuasive," he says, is when scientists from the US Lawrence Livermore National Laboratories and Los Alamos National Laboratory, both specializing in nuclear weapons, present simulation models which suggest that nuclear winter would occur.

CRITICS OF THE THEORY

The nuclear winter concepts presented by Crutzen and Birks, by TTAPS, by Aleksandrov and others all contained their qualifications, regarding both facts and assumptions, yet they have still not gone unchallenged. Dr. Edward Teller, often referred to as the father of the US H-bomb and a member of the staff of the Lawrence Livermore Laboratory; Dr. S. Fred Singer of George Mason University, Virginia; Dr. John Maddox, editor of the prestigious British scientific journal, *Nature*; and Dr. C.H. Kearny are among many who have expressed varying degrees of skepticism about the nuclear winter theory.

A major concern about "nuclear aftermath" has been that, when the dust and smoke did disappear, reappearing sunlight would contain new dangers for all living things on earth. One of its components is ultraviolet radiation, "light" of a waveband too short to be visible to human eyes but exceedingly dangerous in large doses to all living things. Ultraviolet light is normally absorbed in the upper layers of the atmosphere by a super-active form of oxygen (three atoms in a molecule, instead of two) called ozone. It is widely accepted by the scientific community that, if large quantities of chemically-active combustion products were suddenly injected into the upper atmosphere, they would react with the ozone there and eliminate it.

Estimates are that it would take between two and three years after the smoke disappeared to replace the ozone layer and that great harm could be done to all living things in the meantime. Dr. Teller[9] acknowledges that there would be increases in ultraviolet light, because of the elimination of ozone and that this could, in addition to causing damage to vegetation, result in serious sunburn, and increased incidence of skin cancer and possible damage to sight, if no protective action were taken. He argues, however, that the progressively increasing accuracy of delivery systems is leading to the development of much smaller warheads that would not have the energy release needed to carry combustion products into the stratosphere (the threshold appears to be around 1 MT and there is an increased leaning towards warheads of three to five tenths of a megaton for the US and somewhat larger for the USSR).

Dr. Teller remarks that the nuclear winter theory itself depends on the precept that smoke generated by burning forests and cities will be distributed in the troposphere. Such smoke-laden air, he admits, could raise the temperature at the top of the troposphere from approximately minus 50C or minus 60C to plus 5C. Surface temperatures could drop to minus 30C, because of the absorption by smoke of solar energy. But they might not!

Unlike absorption of ultraviolet radiation, he says, forecasting the behavior of smoke depends on a knowledge of far more complex meteorological phenomena, many of which are imperfectly understood, and on bases for smoke estimation that are at present uncertain. The average residence time for water vapor in the atmosphere is little more than a week and studies made of the disappearance times of man-made smoke also suggest a residence time of one week or less.

TTAPS estimates that a 5,000 MT nuclear war that included cities as targets would produce 225 million tons of smoke and Dr. Teller remarks that the estimated weight of water vapor in northern latitudes from 30° to 70° is 10,000 times that figure. Its residence time of one week would be less than the 10 days required to establish conditions of extreme cold. On this basis, he claims that a mass of naturally-occurring water several thousand times that of war-induced smoke would be available to wash it out.

The US National Centre for Atmospheric Research, using a model that includes oceans and winds, found the extent of predictable temperature reduction to be two to ten times less severe than that predicted by TTAPS, depending on the season.

Dr. Teller and some of his colleagues at Lawrence Livermore assert that the calculations on which the nuclear winter theory are based do not properly take account of the major cleaning effects of water vapor that are themselves smoke-induced, nor the influence of the oceans and winds during the time needed for smoke to spread world-wide. While not excluding the possibility of nuclear winter, Teller considers arguments for it to be "dubious rather than robust." He does agree that a decrease in temperature of 5-6 degrees in latitudes 30°-70° North (one-tenth of that suggested by TTAPS) could lead to crop failure and famine but he argues that "speculative theories" of world-wide destruction — even the end of life as we know it on Earth — when used as a call for a particular kind of political action, serve neither the good reputation of science nor dispassionate political thought.

Dr. S. Fred Singer, one of the most outspoken critics of the nuclear winter hypothesis, is vice chairman of the US National Advisory Committee on Oceans and Atmosphere. Although his views have run into heavy criticism by proponents of the nuclear winter theory, some of them could be pertinent. He has stressed for example, the "extreme difficulty" of making global predictions of the environmental effects of a nuclear exchange. The range of uncertainties, he says, is so great because of the set of basic assumptions and "what has been left out in discussion of the physics of the situation." Predictions, he says, are not particularly useful.[11,12]

According to Singer the assumptions used in the TTAPS study virtually guarantee the occurrence of a nuclear winter. They specify:

1) Sufficient smoke to cut off nearly all sunlight;
2) Sufficient injection altitude to allow the smoke to survive;
3) Uniform distribution through latitudes 30° to 70° North; and
4) Explicit neglect of any "greenhouse effect" which would counteract surface cooling (for example, by specifying smoke particles that yield negligible opacity to heat.)

He provides evidence[13] indicating that:

a) The lifetime of smoke will be affected by the fact that lofting to an altitude of more than 5 km is unlikely, except in special atmospheric conditions. (Deliberately set large forest fires involving 16,000 hectares in Chapleau, Northern Ontario, in August 1985, however, produced a "mushroom cloud" that was estimated to have reached an altitude of 6 km);
b) As a rule, and especially in the presence of wind, smoke below 5 km altitude will usually be removed by rainout in a matter of days;
c) Non-uniform, low-lying smoke could produce a greenhouse effect;
d) There should be a greatly enhanced greenhouse effect, even if smoke clouds reach a higher level; and
e) The intrinsic opacity of smoke to infra-red radiation could be greatly affected by a shift in size distribution.

Dr. Singer points out that 200 thousand million tons of particulate matter are injected annually into the atmosphere. He says that, on the basis of a recent analysis of the NRC baseline scenarios, he has to conclude that any major climatic effects would be short-lived, that surface temperature changes would be minor, and that there would be neither deep freezes nor quick freezes. His further and highly controversial conclusion is that there would, instead, be an appreciable likelihood of surface warming . . . a nuclear summer.

STRATEGIC IMPLICATIONS

Two other critics of the TTAPS hypothesis are strategic analyst Francis P. Hoeber, a member of the US President's General Advisory Committee on Arms Control and Disarmament; and Robert K. Squire, formerly of the Lawrence Livermore National Laboratories, who has worked for two decades in the field of arms control.

In a recent article in the *Strategic Review*,[14] they point out that the original thesis of nuclear winter, as put forward by Dr. Sagan and others, rested on a highly simplified model of an enormously complex phenomenon. They question how computers that

cannot support accurate long-range weather forecasts in atmosphere undisturbed by huge nuclear detonations could possibly be expected to predict global effects in the very special situations that have been predicated.

Nevertheless, they stress, there are serious strategic implications stemming from uncertainty. The policies and plans of governments are based on many factors, including judgements about the consequences of actions. In this area it is impossible to formulate specific policies based upon scientific hypotheses that cannot be tested except during a nuclear war. However, a government which has been persuaded that the nuclear winter hypothesis has some validity is not going to launch an all-out attack, even in the face of a presumed threat, if this will destroy the purpose of some temporary military gain. On the other hand, a country whose government has been persuaded that the hypothesis is not valid might see wisdom in striking a country whose morale and willingness to defend itself has been undermined.

A situation in which both superpowers believe in nuclear winter should, in the opinion of Hoeber and Squire promote stability, since resort to nuclear war would be a disaster for both.

The Canadian Department of National Defence, in a study paper contributed to the Royal Society of Canada report,[15] stresses the importance of deterrence in Western defence policy.

"Because Canadian and other North Atlantic Treaty Organization governments have been able to find no surer practical method of prevention of war than nuclear deterrence, deterrence has become the centrepiece of Western security policy," it states. "If one believes in the possibility of grave threat and yet aspires to continue in peace and freedom — neither red or dead — deterrence centred on nuclear weapons, however unlikeable, is the safest system within our reach."

The study draws attention to an "inescapable paradox." If weapons are not capable of realistic use, they cannot deter. The more likely it is that capabilities will be used, if required, the less likely it is that the need will arise.

The DND study examines what it sees as the implications for Western defence policy if the scientific findings of the nuclear winter hypothesis are accepted, and reaches the following conclusions:

a) Strategic policy will not be affected in any profound manner. The concept of nuclear deterrence will not lose its validity or resiliency; nor are there likely to be any major implications for the strategy of flexible response.
b) The disincentive to all-out use of huge nuclear arsenals will be strengthened; indeed, there may be recalculations of the number and types of weapons needed to apply deterrence at levels lower than those at present. The study says, however, that the very large reductions that have been urged by some would weaken deterrence.
c) If the intercontinental strategic (nuclear) deterrents now deployed by the superpowers are substantially reduced in strength, or if their use comes to be considered inconceivable, the importance of theatre-based weapons, including those of the United Kingdom and France (and China) becomes enhanced.
d) Targeting policy may be altered, with even less priority attaching to the use of ground bursts, large yield weapons and the targeting of cities.
e) The threshold for climatic effects of 200 to 2,000 warheads could become a target for nuclear arms reduction.

In considering the further strategic implications of the nuclear winter concept, it must be assumed that, in any world where there is some sanity left, an awareness of the consequences for *all*, both friend and foe, of any large scale strategic use of such weapons will be a substantial deterrent to their use.

Indeed, to many defence planners, the concept is anti-climactic since many of them have assumed that the prospects for survival would be minimal if deterrence failed and nuclear war ensued. On the other hand, the concept has caused some strategic thinkers to reassess the policy of massive retaliation with warheads of high megatonnage. There would be no sanctuary — a superpower could not isolate itself from the effects of its own weapons: the oft-used metaphor of nuclear war as mutual suicide would become literally applicable. The necessity for restraint by both adversaries becomes an even more crucial necessity.

A related implication concerns the possibility of the use of nuclear weapons in response to an enemy's conventional attack: the nuclear winter concept gives pause to those who contemplate the "first-use" of nuclear weapons. It also adds weight to the arguments of those who would strengthen the balance of conventional forces between the superpowers.

The production of high-yield nuclear bombs has been questioned, and a great deal of work done on the development of smaller, more accurate warheads. Because the US has opted for accurate, low-yield warheads, it has a theoretical advantage in the sense that more of its arsenal would be usable. The USSR by contrast has a greater proportion of its nuclear arsenal in high megaton weapons, the use of which would soon cross the nuclear winter threshold.

The nuclear winter theory and its strategic implications have reinforced the public's awareness of the risks involved in any large-scale nuclear exchange. It may well be that one result of this awareness will be a return to the concept of minimum deterrence. And in the end, the theory cannot help but reinforce the notion voiced on many occasions by many world leaders that "a nuclear war cannot be won and must never be fought."

FURTHER READING

For those interested in the subject of nuclear winter and all its implications, the US National Research Council 191-page report[6], the 382-page volume of the Royal Society of Canada[7], and a recently published book (1985) called *Nuclear Winter* by Mark A. Harwell[16] provide a wide range of opinions and reference material, even though, like all encyclopedias, they are dated. The Canadian report contains some very important recommendations:

- Canada is especially vulnerable, notably in agriculture, forestry and ocean resources. It has to collect and evaluate more data that is particularly pertinent to the Canadian situation but Canada must also make use of special Canadian skills to contribute to the international debate.
- Canada should support fully any action by the United Nations to promote a better understanding of the implications of the nuclear winter hypothesis and its impact on strategic questions.
- Canada should continue to support the initiatives of the International Council of Scientific Unions.
- Canada must, through its various relevant organizations, promote discussion within the academic, scholarly, scientific and technical communities.
- Canada should, through its emergency planning agencies, re-examine its preparedness in the light of the nuclear winter hypothesis.
- Canada should consider the maximum possible hardening of essential communications systems against electromagnetic pulse and other damage.
- Canada should resist the argument that any move to improve social preparedness admits the inevitability of nuclear war.

The Committee makes numerous specific technical recommendations regarding areas of special vulnerability. Canada can, for example, do far more research on the behavior of forest fires, an area in which it has already made significant contributions. Canada possesses in its Atmospheric Environment Service some of the best facilities in the world for modelling atmospheric behavior and could make major contributions to the world knowledge. Canadian scientists need to learn much more about the effects that changes in climatic conditions do have and could have on the biosphere. Most important of all, says Dr. Kenneth Hare, chairman of the Royal Society Committee, Canada must exert itself in every way possible to ensure that nuclear winter shall never occur.

In September 1982, the General Assembly of the International Council of Scientific Unions (ICSU) called upon its Executive Board to arrange for the preparation of an unemotional, non-political, authoritative and readily understandable statement of the effects that might be expected to result from even a "limited" nuclear war. That report, *The Environmental Effects of Nuclear War*, published in two parts by John Wiley Limited, England, under the aegis of the Scientific Committee on Problems of the Environment (SCOPE), one of the 10 scientific committees of ICSU, is now available in Canada.

The first volume deals with the physical aspects of the environmental impact of nuclear war. The second examines the biological impacts, including the ecological and agricultural effects. A third volume, to be published later in 1986, will spell out the story in non-technical language. The first two volumes do little to dispel the anxieties expressed in the earlier reports of the US National Academy of Sciences or the Royal Society of Canada. They do, however, underline the uncertainties contained in the assumptions on which any conclusions can be based. They have been described by the authors as "the first attempt by an international scientific group to bring together what is known, and what must still be learned, about the possible global environmental effects of nuclear war." It is intended as a point of departure, rather than a completed investigation.

See also the following:

- Dan Horowitz and Robert J. Lieber, "Nuclear Winter and the Future of Deterrence," *Washington Quarterly*, Summer 1985, pp. 59-70.
- Colin S. Gray, "The Nuclear Winter Thesis and U.S. Strategic Policy," *Washington Quarterly*, Summer 1985, pp. 85-96.
- *Nuclear Winter*, Joint Hearing of the Committee on Science and Technology and the Committee on Interior and Insular Affairs, US House of Representatives, 14 March 1985, US Government Printing Office, Washington, 1985.

ACKNOWLEDGEMENTS

The author would like to acknowledge with special thanks the assistance of Dr. Kenneth Hare, Provost of Trinity College, University of Toronto; Dr. Thomas Hutchinson, Institute for Environmental Studies, University of Toronto, and Professor of Botany; Dr. S. Fred Singer of George Mason University, Virginia; and Dr. Andrew Forester, Institute for Environmental Studies, University of Toronto, and Dartside Consulting, who was kind enough to comment exhaustively on the typescript. Only the author can be held responsible for what emerged.

NOTES

1. Turco, R.P., Toon, O.B., Ackerman, T.P., Pollack, J.C., and Sagan, C., "Nuclear Winter: global consequences of multiple nuclear explosions," *Science* 222, 1983, pp. 1283-1292. [The so-called TTAPS paper, an acronym for the authors' initials].
2. Ehrlich, P.R., Harte, J., Harwell, M.A., Raven, P.H., Sagan, C., Woodwell, G.M., Berry, J., Ayensu, E.S., Ehrlich, A.H., Eisner, T., Gould, S.J., Grover, H.D., Herrera, R., May, R.M., Mayr, E., McKay, C.P., Mooney, H.A., Myers, N., Pimentel, D., and Teal, J.M., "Long-term biological consequences of nuclear war," *Science* 222, 1983, pp. 1293-1300. [This and the TTAPS paper (1) above, published concurrently, constitute the definitive statements of the nuclear winter hypothesis.]
3. Martin, T.Z. and Kieffer, H., "Thermal infra-red properties of the Martian atmosphere," *J. Geophys. Res.* 84, 1979, pp. 2843-2852.
4. Alvarez, L.E., Alvarez, W., Asaro, F., and Michel, H.V., "Extraterrestrial cause for the Crustaceous-Tertiary extinction," *Science* 208, 1980, pp. 21-5.
5. Crutzen P.J., and Birks, J.W.: "The atmosphere after a nuclear war: twilight at noon," *Ambio* 11, 1982, pp. 115-25.
6. *The Effects on the Atmosphere of a Major Nuclear Exchange*, 1985, US National Academy of Sciences/National Research Council.
7. *Nuclear Winter and Associated Effects: a Canadian Appraisal of the Environmental Impact of Nuclear War*, 1985, Royal Society of Canada/La Société Royale du Canada.
8. Aleksandrov, V.V., "Global shield causes nuclear winter"; presented at the Conference on Nuclear Deterrence: New Risks, New Opportunities, 5-7 September 1984, University of Maryland [paper reproduced in (7) above].
9. Teller, E., "Widespread after-effects of nuclear war," *Nature* 310, 1984, pp. 621-624.
10. Kearny, C.H., Letter to Editor, *Science* 227, 1984, pp. 356-358.
11. Singer, S.F., Letter to Editor, *Science* 227, 1984, pp. 356-358.
12. Singer, S.F., "Nuclear Winter and Nuclear Freeze," *Disarmament: A Periodic Review*, United Nations, 1984.
13. Personal communication.
14. Hoeber, F.P. and Squire, R.K., *Strategic Review*, Summer 1985, pp. 39-46.
15. *Nuclear Winter: A Canadian Appraisal of the Environmental Impact of Nuclear War*, Royal Society of Canada, 1985, pp. 352-60.
16. Harwell, M.A., *Nuclear Winter: The human and environmental consequences of nuclear war*, Springer-Verlag, 1985.

Leonard Bertin is a freelance scientific writer and consultant.

The views expressed in this paper are the sole responsibility of the author, and should not be taken to represent the views of the Institute and its Board.

Published by the Canadian Institute for International Peace and Security. Additional copies are available from the Institute: 307 Gilmour Street, Ottawa, Ontario, K2P 0P7.

Le présent exposé est également publié en français.